ANNEX 1

RESEARCH PUBLICATIONS PRODUCED DURING THIS STUDY

1) **Drucker, B.R. & Hitchcock, D.R.** (1996) Environmental Management of sand and gravel and aggregate resources on the Outer Continental Shelf: The United States versus The United Kingdom experience and ongoing co-operation between the two countries. *Oceanology International 96. The Global Ocean-Towards Operational Oceanography. Conference Proceedings Vol 1 Spearhead Exhibitions Ltd. Surrey KT3 3LZ.* **ISBN 0 900254 12 2.** pp. 153 - 164

2) **Hitchcock, D.R.** (1994) Investigation of surface plumes associated with marine aggregate production in the United Kingdom - Preliminary results Report to ARC Marine Ltd, United Marine Dredging Ltd & South Coast Shipping Co. Ltd. **Ref No. 94-555-33** Coastline Surveys Ltd. 15pp

3) **Hitchcock, D.R.** (1997) Aspects of sediment disturbance associated with marine aggregate mining. Unpublished PhD Thesis, University of Wales, 213pp

4) **Hitchcock, D.R. & Dearnaley, M.P.** (1995). Investigation of benthic & surface plumes associated with marine aggregate production in the United Kingdom: Overview of Year One *Proceedings of XVth Information Transfer Meeting, Gulf Coast Region INTERMAR*, New Orleans, USA. 10pp

5) **Hitchcock, D.R. & Drucker, B.R.** (1996) Investigation of benthic and surface plumes associated with marine aggregates mining in the United Kingdom. In: *The Global Ocean-Towards Operational Oceanography. Proceedings of the Oceanology International Conference, 1996. Spearhead Exhibitions Ltd. Surrey KT3 3LZ.* **ISBN 0 900254 12 2. Vol. 2.** pp. 221 – 234

6) **Hitchcock, D.R., Newell, R.C. & Seiderer, L.J.** (1998) Overspill Outwash Study Area 430 (Southwold). Confidential report to United Marine Dredging Ltd & South Coast Shipping Co. Ltd. **Ref No. 98-674-103** Coastline Surveys Ltd. 31pp

7) **Newell, R.C., Hitchcock, D.R. & Seiderer, L.J.** (1998) Organic enrichment associated with outwash from marine aggregate dredging: a probable explanation for surface sheens and enhanced benthic production in the vicinity of dredging operations. *Marine Pollution Bulletin,* in press

8) **Newell, R.C., Seiderer, L.J. & Hitchcock, D.R.** (1998) The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed. *Oceanography and Marine Biology Annual Review*, ***36***, pp. 127-178

Hitchcock, D.R. & Hermiston, A.R. (1997) Presentation of study results to MAFF, Dredging Industry and Regional Sea Fisheries Groups, Chichester

PAPER (7) INCLUDED IN THIS REPORT (FOLLOWS)

Organic Enrichment Associated with Outwash from Marine Aggregates Dredging: A Probable explanation for Surface Sheens and Enhanced Benthic Production in the Vicinity of Dredging Operations.

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ABSTRACT.

Despite concern over the impact of marine aggregates dredging on benthic community composition within dredged areas, the scale of impact outside the boundaries of the dredged area from the settlement on the sea bed of fine material temporarily suspended by the dredging and screening process is poorly understood. Most recent studies of dispersion of sediment plumes generated by marine aggregates dredging, including those reported here, suggest that the area of impact of outwash from dredging activities is smaller than estimates based on Gaussian diffusion models, especially when the proportion of silt and clay in the deposits is low.

This paper presents evidence which suggests that the "far field" visibility of the dispersing plume is associated with organic enrichment derived from fragmented marine benthos discharged with the outwash water. These are the first direct measurements of the organic composition of the outwash from a marine aggregates dredger, and are based on a cargo loaded from a hitherto largely unexploited site to the east of Southwold, Suffolk. The values therefore probably represent maximal concentrations for coastal deposits and reach concentrations of as much as 1.454 grams AFDW per litre of which 0.007 grams per litre (0.48%) comprises lipids.

Such material appears to be of sufficient concentration to match the known removal of benthos from the dredged sediments, and is clearly sufficient to account for the presence of a detectable "plume" beyond the point at which inorganic solids have fallen to background levels. The fact that significant quantities of lipids are associated with this material may reduce the rate of sedimentation of fragmented material and account for the commonly-observed surface "sheen" at the extremity of the dispersing plume. Even allowing for the dispersion which must occur downstream from the dredger, it seems likely that the organic matter derived from fragmented invertebrates in the dredger outwash may account for the enhanced species diversity and population density of benthic invertebrates recorded by others beyond the boundaries of dredged areas.

INTRODUCTION

The increased exploitation of marine deposits for aggregates, and the physical and biological impacts of dredging works has been widely reviewed (Dickson & Lee, 1972; Shelton & Rolfe, 1972; Cruikshank & Hess, 1975; de Groot, 1986; Nunny & Chillingworth, 1986; ICES, 1993; Newell *et al*, 1998). Essentially, the physical impact of dredging works is dependent partly on the method of dredging, and partly on the amount and grade of deposits rejected by screening, and overspill from the hopper. A typical modern sea-going aggregates dredger operating in U.K. waters is self-contained and uses a centrifugal pump delivering approximately 7750 $m^3.h^{-1}$ to lift the aggregates from the sea bed into a hopper of approximately 5,000 tonnes capacity, a process which takes 2-8 h depending on the amount of screening which is required to attain a cargo load of suitable quality.

Estimates by Hitchcock & Drucker (1996) suggest that for a suction trailer dredger of 4,500 tonnes hopper capacity operating on the Owers Bank, off the south coast of U.K., approximately 750 tonnes of solids are discharged through overspill and as much as 7,223 tonnes through the screening reject chutes. Water discharge is 21,387 tonnes from overspill and 13,499 tonnes through screening. The screened material is thus discharged in relatively high concentration through a reject chute whilst a larger volume containing a relatively low concentration of suspended solids overflows from the hopper.

The impact of such dredging on benthic communities varies widely depending, among other factors, on the intensity of dredging and the type of community which occurs in a particular area. Most estimates indicate that both maintenance dredging and marine aggregates dredging operations can be expected to result in a 30-70% reduction of species diversity, a 40-90% reduction in the number of individuals, and a similar reduction in the biomass of benthic communities in the dredged area.

Despite concern over the impact of marine aggregates dredging on benthic community composition within dredged areas (see ICES, 1992a;b), the probable scale of impact outside the boundaries of the dredged area from the settlement on the sea bed of fine material temporarily suspended by the dredging and screening processes is poorly understood. In its simplest form, the settlement velocity and residence time of particles discharged during screening and from hopper overflow can be estimated from Stoke's law. If the residence time of particles in the water column is known, the duration and speed of local currents and turbulence will then determine the excursion pattern before settlement. Estimates of dispersion of material based on these Gaussian diffusion principles suggest that coarse material settles rapidly below the point of discharge from the dredger, a feature which has been verified in studies at sea (Gajewski & Uscinowicz, 1993). Very fine sand particles have been estimated to travel up to 11-km from a dredge site at Owers Bank off the south coast of U.K whilst similar estimates based on Gaussian diffusion models for fine silt particles (<0.063 mm) suggest that this material could remain in suspension for up to 4-5 tidal cycles and be carried for as much as 20-km from the point source of discharge (H R Wallingford, 1993; cited in Hitchcock & Drucker, 1996).

Most recent studies on the dispersion of sediment plumes generated by marine aggregates dredging suggest, however, that the area of impact of outwash from dredging activities is smaller than estimates based on Gaussian diffusion models, especially when the proportion of silt and clay in the deposits is low. This appears to be due to complex cohesive properties of the discharged sediment particles that settle on the sea bed as a density current and reflects flocculation and initial entry velocity of the overspill/reject mixtures into the water column. The discharged material thus does not conform to settlement rates based on specific gravity and size of the component particles themselves (Land *et al*, 1994; Whiteside *et al*, 1995; Hitchcock & Dearnaley, 1995; Hitchcock & Drucker, 1996). Such studies show that settlement of the inorganic particulate load discharged from marine aggregates dredging is mainly confined to a distance of a few hundred metres from the point source of discharge.

The surface plume is, however, visible as a "slick" for a considerable distance beyond that at which suspended inorganic solids have fallen to background levels. This has been ascribed to the possibility of air bubbles and entrainment of organic matter into the water column from the dredging process (Hitchcock & Drucker, 1996).

It is the purpose of this paper to present evidence which shows that this "far field" visibility of the dispersing plume is associated with organic enrichment probably derived from fragmented marine benthos discharged with outwash water. Such material appears to be of sufficient concentration to match the known removal of benthos from the dredged deposits, and may account for the enhanced benthic species diversity and population density reported for deposits surrounding dredged areas (see Poiner & Kennedy, 1984).

MATERIAL & METHODS.

1. Continuous Backscatter Profiling (CBP).

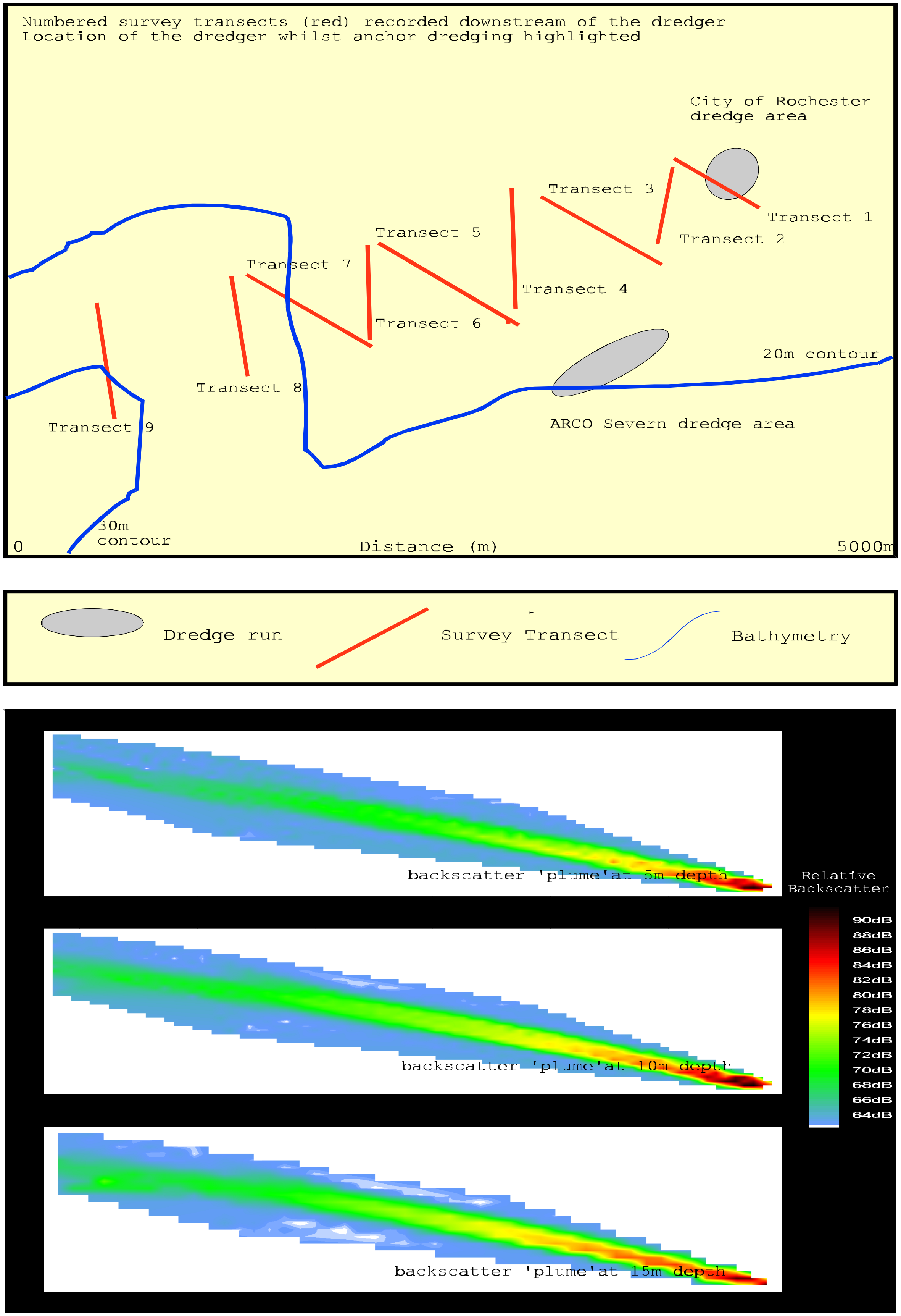
Acoustic Doppler current profiling techniques utilise the transmission of a beam of sound into the water column by 3 or 4 highly directional (2.5^{o} beam width) transducers arranged in a "Janus" configuration, inclined at 30^{o} to the vertical. Backscattered sound from plankton, small particles, air bubbles and small-scale heterogeneities in the water ("scatterers") are recorded by the transducer. The primary function of Doppler current profiling techniques is to record continuous current velocities through depth and, depending on the equipment, dynamically using a moving boat. This technique is widely used and is gaining increasing acceptance worldwide. A secondary function of some systems enables the operator to display the acoustic strength of the returned signals as affected by the suspended particulate matter, and hence record variations in scatterers, generally interpreted as suspended solids concentrations (see Land *et al*., 1994; Whiteside *et al*, 1995; Weiergang *et al*, 1995).

Acoustic backscatter transects reported in our study were obtained using an RDInstruments 1200 kHz Broadband Acoustic Doppler Current Profiler (ADCP) which was operated from a survey vessel downstream of a marine aggregates dredger during normal loading operations on the Owers Bank, off the south coast of U.K. during 1995. Additional samples of the composition of the outwash to verify the predictions made from the Owers Bank data were obtained from a dredger operating off Southwold, Suffolk in April 1998. Doppler current profiling techniques and acoustic backscatter measurements have been used extensively for observation of the distribution of suspended particulate matter, particularly zooplankton following the work of Flagg & Smith (1989). Similar techniques have recently been used for observations on suspended solids associated with dredging and dredged material disposal operations, particularly cohesive sediments (Thevenot & Kraus, 1993).

A number of investigators have attempted to correlate backscatter sound strength (dB) of the returned signal with suspended solids concentration (mg/l) with varying degrees of success (Thevenot & Johnson, 1994; Tubman *et al*, 1994). Land *et al* (1994) reported statistically acceptable correlation with optical silt meters and water samples for sediments in the range of 5-75 mm with a mean particle diameter of 10 mm and concentrations up to 1000 mg/l. Lohrmann & Huhta (In: Tubman *et al*, 1994) calibrated a 2.4 MHZ Broadband ADCP in a purpose-built laboratory calibration tank using material obtained by grab from the sea bed of the site to be studied. Although suspended solids concentrations determined by the ADCP were considered to agree "reasonably well" with the water sample analysis, the maximum error was considered to be $\pm$ 60% at 50 mg per litre. Thevenot & Johnson (1994) suggest that flocculation of the material could be a contributing factor to the differences between field and laboratory calibrations. Detailed discussion of the principles of using the acoustic backscatter function of the ADCP™ can be found in Land *et al* (1994) and Weiergang *et al* (1995).

In the study reported here, the acoustic backscatter function of the ADCP™ has been used to display a real-time semi-quantitative graphical representation of the gross morphology of the plume in relation to distance and water depth across a number of plumes generated by dredgers operating on the Owers Bank, off the south coast of U.K (see also Hitchcock & Dearnaley, 1995; Hitchcock & Drucker, 1996; Hitchcock, 1997). Continuous observations of the strength of acoustic signal returned by particles in the water column were processed in real-time on screen displays with horizontal time and vertical water depth axes. The colouring of the individual boxes of data (shown in Figure 1) are user-configurable and relative to the acoustic strength of the returned echoes, and hence to the amount of "scatterers" in the water column. Importantly, this may include organic and inorganic particulates, air bubbles etc, so that complementary samples of suspended solids are required to interpret the plume morphology.

Figure 1: Relative positions of the survey vessel tracks and position of the anchored dredger during monitoring



Broadband 1200 kHz ADCP techniques do not return valid data within the lowest 6% of the water column. Within the context of this paper, our observations do not include this boundary region of the water column. A different approach is required in order to assess the behaviour of suspended and settling material within such a layer at the sediment-water interface.

2. Positions of the Survey Data.

To produce competent analysis of the ADCP™ data, the position of the ADCP™ survey vessel and the dredger vessel was fixed by Global Positioning System (GPS) techniques operating in Differential mode (dGPS). A position accuracy of better than 5 metres was attained for both survey vessel and operating dredger.

3. Suspended Solids.

Water samples were taken from the hopper spillways by three successive dips of a 20 litre bucket lowered directly into the flow, taking care not to obtain more than 3 litres of sample, and transferred to a single 10 litre container. A series of samples were taken at known times during the entire loading process and gave an even spread of data throughout the load. Separate samples of up to 2 litres of overspill water were taken for organic analysis. Due to difficulties of sampling in the high velocity flow from the screening reject chutes, direct measurements on material discharged by this route are the subject of a further field experiment to be conducted in the near future.

Two samples of approximately 2 litres of sea water were taken at depths of 4 m, 8 m, 12 m, 16 m and 18 m depth at varying distances up to 3.5 km downstream of an operating dredger and the size distribution of suspended solids determined by standard gravimetric techniques (see also Hitchcock & Dearnaley, 1994; Hitchcock & Drucker, 1996; Hitchcock, 1997). These data were then compared with background samples taken each day before dredging commenced, and with samples taken upstream of the dredger. Background suspended solids concentrations were between 5-10 mg per litre.

4. Ash-Free Dry Weight.

Water samples of approximately 2 litres were collected from the hopper spillways and immediately deep-frozen in plastic containers. These were then transported frozen to the laboratory for analysis. The water samples were filtered through pre-weighed GF/F filters to remove the sedimentary particles > 0.7 mm in diameter. The sediments were dried in an oven at 40^{o} C until a constant weight was achieved. The filters were then heated in a muffle furnace to 500^{o} C for 24 h. The ash-free dried weight was calculated from the difference between the sediment weights.

5. Lipid Analysis.

Water samples collected and deep-frozen as described above were filtered through a glass fibre filter to remove the suspended solids in the sample. The volume extracted was recorded before beginning the filtration process. The water sample was then double extracted into dichloromethane, concentrated on a rotary evaporator, and blown down to dryness under a stream of nitrogen. The sediments were also extracted using dichloromethane and these extracts were combined with the lipids from the water.

6. Data Processing.

The RD Instruments' data acquisition software "Transect" is used to generate many of the graphics of relative backscatter and current velocity. However, in order to assess depth-related variations of relative acoustic backscatter, current velocity and current direction, two in-house software routines have been developed in order to further analyse the ASCII output from the Transect software. These are Velocity MAP (VMAP) and Backscatter MAP (BMAP). The latter program is concerned with analysis of depth relative variation of the relative backscatter recorded by the ADCP™. Processing of the Transect files involves generating an ASCII file which contains, in tabular format, all the easting, northing, depth and relative backscatter values, as well as all other system and observed variables. These are then modelled using a simple contouring package to produce pixilated images of the contoured relative backscatter levels at required depths for comparison (see Hitchcock, 1997).

RESULTS

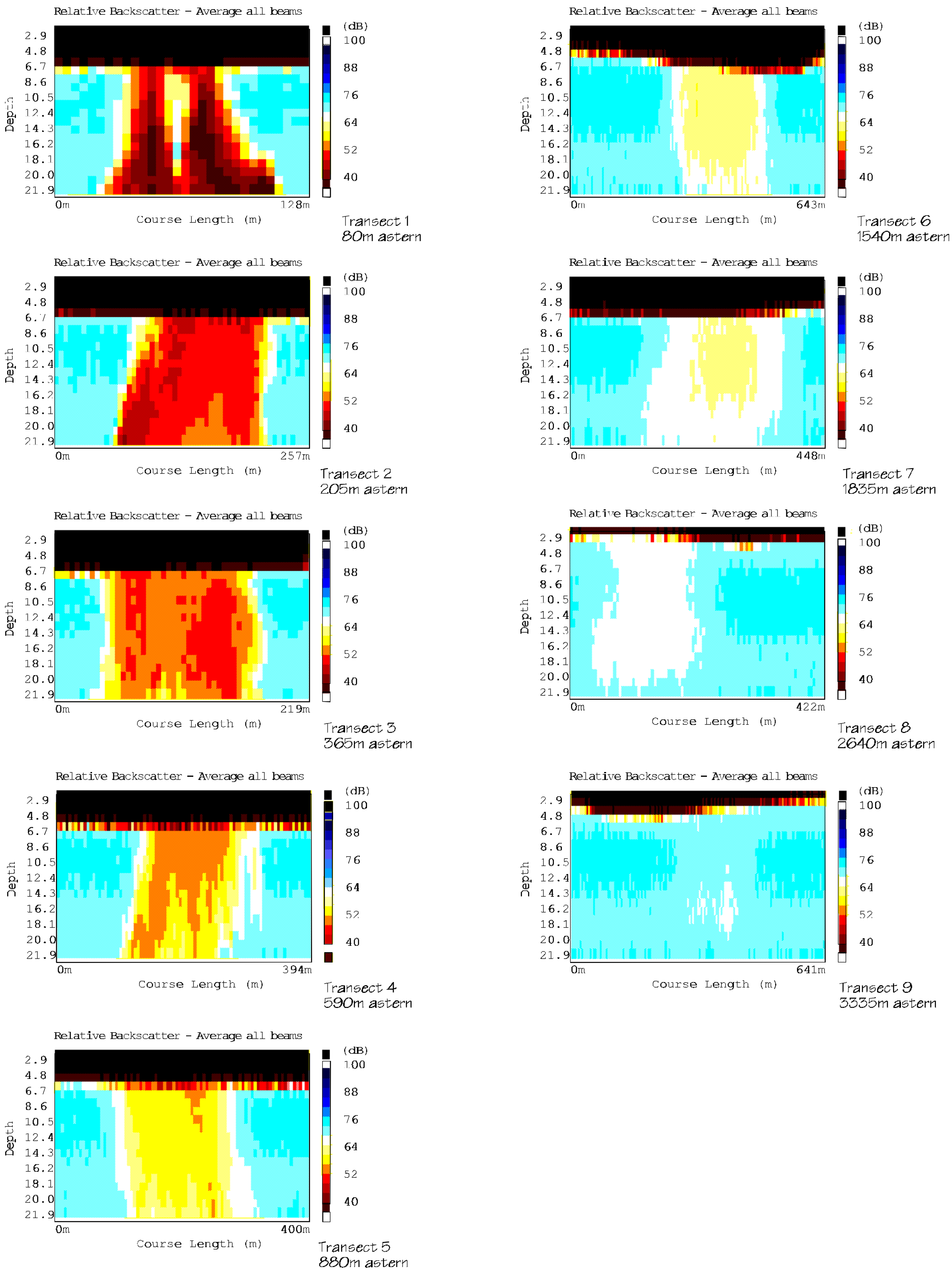
1. DEFINITION OF PLUME MORPHOLOGY.

The results of a plume monitoring programme carried out behind a trailing suction hopper dredger TSHD dredger *City of Rochester* operating whilst anchored on 21st August 1995 are summarized in Figures 1-3. The Acoustic Backscatter Transects were obtained using an RDI 1200kHz Broadband Acoustic Doppler Current Profiler (ADCP). A series of 9 transects was recorded across the plume. Simultaneous current measurements analysed at the start and end of the transect indicate a mean surface flow of 53 cm/sec reducing to 36 cm/sec and a mean bottom flow of 35 cm/sec reducing to 23 cm/sec in a direction of 250 degrees. Water sampling data indicate that at less than 100 m from the dredger, total suspended solids concentrations were 480-611 mg/l in the lower water column and 80-340 mg/l in the upper water column.

Figure 1 shows the distribution of the transects and the horizontal distribution of contours of relative backscatter in relation to the dredger, at depths of 5m, 10m and 15m below the surface. The corresponding vertical depth profiles at varying distances up to 3,350 metres astern of the dredger are shown in Figure 2.

The variation of suspended sediment concentration measured independently by water sampling at various depths and with distance behind the dredger is shown in Figure 3. From this it is clear that at 250 m astern of the dredger the majority of suspended solids are not detectable within the water column above the 6% water depth ADCP data corruption zone above the sea bed. Inspection of Figure 3 also shows that even the finest silt-sized particles largely disappear from the water column within a distance of 480 metres downstream of the dredger.

Figure 2: ADCP cross sections of the relative acoustic backscatter decreasing in intensity with range away from the dredger and becoming more disperse. Identifiable suspended solids concentrations reduce to background at 300m to 500m from the dredger. Sampling has shown that the ADCP is probably discriminating elevated levels of organics beyond this region and as far downstream as 3000m-3500m.



Returning to Figures 1 & 2, it is clear that the acoustic backscatter results still indicate a significant plume of dispersing material beyond the 480 metres where the inorganic particulate load was considered to have reached background levels. This "plume" was detectable visually and by ADCP techniques for a distance of 3335 metres astern of the dredger. This was considered to be due to either aeration (considered unlikely at such distances), physico-chemical precipitates or entrainment of organic matter from the sediments when first reported by Hitchcock & Dearnaley (1994) and Hitchcock & Drucker (1996). The following section presents some estimates of the quantities of organic matter which could be attributable to benthic invertebrates fragmented by dredging within the dredged area.

2. ESTIMATES OF ORGANIC ENRICHMENT BASED ON BENTHIC BIOMASS.

There are relatively few studies where the biomass of benthic invertebrates has been quantified in sufficient detail to allow some estimates of the contribution which they might make to organic enrichment in the dredger outwash. Lees *et al* (1992) have reported that some components of the fauna in the outwash of the suction trailer dredger *Arco Tyne* appeared undamaged, but that worms and many crustaceans appeared susceptible to physical damage as a direct consequence of the dredging operation even if they were subsequently returned to the sea in the outwash. For the purposes of estimating the potential contribution represented by fragmentation of the benthos, it is probably realistic to use figures which are available for biomass reduction in dredged areas. These suggest a figure of some 70-90% reduction of biomass within the boundaries of dredged areas (for review see Newell *et al*, 1998).

Table 1 shows figures for the biomass of benthic macrofauna recorded from coastal sediments in U.K waters prior to dredging. Data are expressed as the maximum values recorded, the minimum values and the mean ash-free dry weight (AFDW) in grams for up to 70 samples taken at 50 stations using a 0.2 m^2 Hamon grab. Data for the biomass have been calculated from the blotted wet weight using conversion factors in Eleftheriou & Basford (1989). Values for a site off Lowestoft, Norfolk have been recalculated from Kenny & Rees (1996), all other values are recorded in reports by Newell & Seiderer (1997a-d).

Table 1. Table showing the biomass of benthic macrofauna recorded from coastal sediments in UK waters prior to dredging. Data are expressed as the maximum values recorded, the minimum values and mean Ash-free Dry Weight (AFDW) in grams for up to 70 samples taken at 50 stations using a $0.2m^2$ Hamon Grab which took an average sample of 17.7 kg sediment. Data for the biomass have been calculated from blotted wet weight using conversion factors from Eleftheriou & Basford (1989). The mean value for all stations has been calculated from the total data where N=242.

SITE	**AFDW of Benthos (g per $0.2m^2$)**					**SOURCE**
	Max	**Min**	**Mean**	**S.D.**	**N**	
Lowestoft, Norfolk	-	-	4.4	-	-	Recalculated from Kenny & Rees (1996)
St.Catherine's, Isle of Wight	48.45	0.03	5.59	8.97	52	Newell & Seiderer (1997a)
Folkestone, Kent	23.5	0.01	4.95	23.55	70	Newell & Seiderer (1997b)
Orford Ness, Suffolk	67.14	0.001	3.18	9.70	60	Newell & Seiderer (1997c)
Lowestoft, Norfolk	21.13	0.01	1.49	3.49	60	Newell & Seiderer (1997d)
MEAN	40.055	0.0127	3.767			
S.D.	21.881	0.0122	14.28			
N	4	4	242			

Inspection of Table 1 shows that the maximum biomass can be as high as 67.14 grams AFDW and as low as 0.001 grams AFDW per 0.2 m^2 Hamon grab sample, reflecting the high variability of benthic community composition in coastal sand and gravels deposits. The average maximum values for all survey areas was 40.06 grams AFDW. The average of the minimum values was 0.0127 grams AFDW and the mean for all 242 samples at all sites was 3.767 grams AFDW per 0.2 m^2 Hamon grab sample.

These data allow some estimates to be made of the likely contribution which fragmented benthos could make to the organic content of outwash from a typical working dredger, assuming complete removal of the benthos along the path of the draghead from the dredger. Field records show that the mean volume of sediment from which the macrofauna was extracted was as follows: St Catherine's, Isle of Wight (not measured), Folkestone, Kent 11.790 litres (SD 5.30; N=133); Orford Ness, Suffolk 13.86 litres (SD 4.31; N=59); Lowestoft, Norfolk 15.13 litres (SD 5.28; N=57). The mean volume sampled per station for all survey areas was 13.6 litres. The specific gravity of the sediments is approximately 1.30, so the average weight of sediment from which the macrofauna was extracted was 17.67 kg. Multiplication by the total amount of sediment processed by a dredger during normal loading operations allows calculation of the biomass of organic matter associated with the dredged material.

Table 2 shows the mass of organic matter (AFDW) estimated to be discharged from a typical marine aggregates dredger of 4,500 tonnes hopper capacity based on the biomass of benthic invertebrates shown in Table 1, the tonnes of sediment processed during a normal loading operation and the volume of water discharged through spillways and screening. Calculations are based on an estimated 12,158 tonnes of solids processed and a total water discharge of 34,866 tonnes (Hitchcock & Drucker, 1996).

Table 2. Table showing the mass of organic matter (AFDW) estimated to be discharged from a typical marine aggregate dredger of 4,500 tonnes hopper capacity. Estimates based on the biomass of benthic invertebrates shown in table 1, the tonnes of sediment processed during a normal loading operation (12,158 tonnes) and the volume of water discharged through hopper spillways and screening chute (34,866 tonnes). The mean value for all stations has been calculated from the total data where N=242.

SITE	**AFDW of Organic Matter estimated to be derived from Benthos**					
	Tonnes per Cargo			**mg AFDW per litre**		
	Max	**Min**	**Mean**	**Max**	**Min**	**Mean**
Lowestoft, Norfolk	-	-	3.0267	-	-	86.809
St.Catherine's, Isle of Wight	32.3284	0.0206	3.8453	995.90	0.5908	110.288
Folkestone, Kent	16.1655	0.0069	3.4051	463.6	0.1973	97.662
Orford Ness, Suffolk	46.1851	0.0007	2.1875	1324.6	0.0197	62.740
Lowestoft, Norfolk	14.5352	0.0069	1.0250	416.9	0.1973	29.398
MEAN	27.55	0.0088	2.592	790.25	0.2513	74.34
S.D.	15.05	0.0084	9.823	431.69	0.2413	281.74
N	4	4	242	4	4	242

Inspection of Table 2 shows that relatively large quantities of organic matter could be derived from fragmentation of the benthos. During a normal loading of 4,500 tonnes of cargo, a maximum of some 46.2 tonnes AFDW of organic matter could be discharged in the 34,866 tonnes of outwash from the dredger. A minimum of 0.0007 tonnes AFDW and an average for all areas of 2.590 tonnes AFDW organic matter discharged per cargo is indicated in Table 2. Since the volume of outwash is known, the concentration of organic matter can be calculated from the biomass data. This indicates that a maximum of 1,324.6 mg AFDW per litre could be derived from the benthic biomass recorded off Orford Ness, Suffolk, and a mean for all areas of 74.34 mg AFDW per litre in the outwash at the point of discharge.

Many of the fragmented marine invertebrates are likely to be rich in lipids, and may thus account not only for the "far field" scatter recorded by ADCP techniques but also the characteristic surface "slick" which can be seen well downstream of the point at which suspended inorganic particle load is indistinguishable from background levels. The following section presents the results of analysis of the outwash from an operational dredger to determine the concentration of organic and suspended solids load which occurs in the outwash of a dredger during normal loading operations.

3. ORGANIC ENRICHMENT OF SPILLWAY DISCHARGES.

Table 3 shows the volume of water, dry weight of particulate matter (grams) and ash-free dry weight (AFDW, grams) of control seawater samples and a series of 20 spillway samples taken during normal loading operations by a modern suction trailer dredger of some 5,000 tonnes hopper capacity. Data are for a cargo loaded off Southwold, Suffolk in April 1998. Values for the background inorganic and organic matter recorded from the control seawater samples have been subtracted in the final column to give concentration of sediment (grams per litre) and organic matter (AFDW mg per litre) in water discharged from the dredger during the course of the loading operation. Samples 1-15 (inclusive) are for an unscreened "all-in" cargo. Samples 16-20 are for outwash from a cargo from which the fine sand component had been removed by screening and discharged through a separate reject chute.

Table 3. Table showing the volume of water, dry weight of particulate matter (g) and Ash-free Dry Weight (AFDW - g) of control seawater and a series of 20 samples of hopper overspill taken during normal loading operations by a modern suction trailer dredger of approx. 5,000 tonnes hopper capacity. Data are for a cargo loaded off Southwold, Suffolk in April 1998. Values for the background inorganic and organic matter recorded from the control sample have been subtracted in the final columns to give sediment concentration ($g.l^{-1}$) and organic matter (AFDW $mg.l^{-1}$) in the water discharged from the dredger during the course of the loading operation. Samples 53-97 (incl.) are for an unscreened "all-in" cargo. Samples 105-135 are for outwash from a cargo from which the fine sand component had been removed by screening and discharged through a separate reject chute.

Sample #	**Reference #**	**Volume of water (ml)**	**Dry weight (g)**	**Weight after combustion (g)**	**Difference (g)**	**Overspill composition**	
						Sediment ($g.l^{-1}$)	**Organic matter ($mg.l^{-1}$)**
Control		620	0.4782	0.3196	0.1586	-	-
1	53	790	4.2665	3.9873	0.2792	4.5322	97
2	56	770	6.1127	5.6126	0.5001	6.7736	393
3	59	830	8.1938	7.5065	0.6873	8.5284	572
4	62	800	8.7111	6.2725	2.4386	7.3251	2792
5	65	730	11.599	8.0563	3.5433	10.5205	4854
6	68	640	6.6583	6.2726	0.3857	9.2854	347
7	71	850	10.221	9.4816	0.7397	10.6393	614
8	74	610	10.978	10.1562	0.8218	16.1340	1091
9	79	810	5.9273	5.4039	0.5234	6.156	390
10	82	770	8.3737	7.7814	0.5923	9.5902	513
11	85	900	5.1144	4.9859	0.1285	5.0245	-
12	88	830	16.315	15.5592	0.7561	18.2305	655
13	91	770	12.969	12.1248	0.8444	15.2310	841
14	94	810	11.751	10.6112	1.1398	12.5847	1151
15	97	710	11.251	10.2055	1.0461	13.8584	1217
16	105	840	6.3182	5.6749	0.6433	6.2403	510
17	115	720	18.570	14.2991	4.2711	19.3445	5676
18	120	1070	17.193	15.5822	1.6115	14.0473	1250
19	130	1000	7.7477	7.2049	0.5428	6.6894	287
20	135	580	32.913	30.2219	2.6914	51.5912	4384
MEAN		791.5	11.059	9.8500	1.2093	12.6163	1454.4
SD		116.9	6.5312	5.9167	1.1364	10.1736	1683.9

Inspection of Table 3 shows that the outwash recorded from the dredger working in hitherto unexploited deposits off Southwold, Suffolk comprised approximately 12.6 grams per litre of suspended solids and as much as 1454.4 mg AFDW per litre of organic matter. This is close to the highest value of 1324.6 mg AFDW calculated to be available from the macrofauna reported by Newell & Seiderer (1997c) for the Shipwash Gabbard area off Orford Ness, Suffolk (see Table 2) and may reflect locally rich benthic resources in the dredged deposits off Southwold.

It is clearly of interest to determine whether the lipid content of the organic matter recorded in the outwash is sufficiently high to account for the characteristic surface "sheen" observed in the far field of dispersing outwash plumes downstream from dredging operations. Table 4 summarises the lipid content of a sample of sea water and a series of 20 samples of hopper outwash taken during the loading operation off Southwold, Suffolk in April 1998. Values for the background lipid recorded from the control sea water sample have been subtracted in the final column to give the lipid (mg per litre) in the water discharged from the dredger during the course of the loading operation. Inspection of Table 4 shows that the lipid content of the outwash samples was highly variable, probably reflecting the type of fragmented invertebrate material discharged at the time the samples were taken. Values as high as 50 mg per litre were recorded, the average for the series of 20 samples being 6.94 mg per litre. Based on this average value, the lipids represent 0.48% of the 1454.4 mg per litre organic matter discharged.

Table 4. Table summarising the lipid content of a sample of seawater and a series of 20 samples of hopper outwash taken during normal loading operations by a modern suction trailer dredger of approx. 5,000 tonnes hopper capacity. Data are for a cargo loaded off Southwold, Suffolk, in April 1998. Values for the background lipid recorded from the control seawater sample have been subtracted in the final column to give the lipid concentration ($mg.l^{-1}$) in the water discharged from the dredger during the course of the loading operation.

Sample #	**Reference #**	**Lipid Concentration ($mg.l^{-1}$)**	
		In Sample	**In Overspill**
Control 1		0.12	-
1	53	0.70	0.58
2	56	0.31	0.19
3	59	50.66	50.54
4	62	0.16	0.04
5	65	0.57	0.45
6	68	26.32	26.20
7	71	0.43	0.31
8	74	0.24	0.12
9	82	0.30	0.18
10	85	0.39	0.27
11	88	0.36	0.24
12	91	45.01	44.89
13	94	4.15	4.03
14	97	0.59	0.47
15	105	3.30	3.18
16	110	5.82	5.70
17	115	0.53	0.41
18	120	0.59	0.47
19	130	0.36	0.24
20	135	0.43	0.31
Table 4 (continued)			
MEAN	-	-	6.941
SD	-	-	15.135

It is now possible to summarise the mass discharges and concentrations of materials from a suction trailer dredger of 5,000 tonnes hopper capacity loading a cargo off Southwold, Suffolk in April 1998. The volume of water discharged is based on the difference between the pumping rate of 7750 m^3 and 5.5 hr loading time recorded during the survey, and an average value of 14,073 tonnes recorded for solids pumped during loading. The results are summarised in Table 5.

Table 5. Table summarising the mass discharges and concentration of materials from a suction trailer dredger of 5,000 tonnes hopper capacity loading a cargo off Southwold, Suffolk, in April 1998. Volume of water discharged is based on the difference between a pumping rate of 7,750 $m^3.h^{-1}$ and 5.5 hr loading time recorded during the survey, and an average value of 14,073 tonnes for solids pumped during loading. Values for sediment in the screening reject chute have been estimated from the cargo loaded and pumped solids.

	Total tonnes discharged per cargo	**Concentration measured in outwash ($g.l^{-1}$)**
Water	28,552	-
Sediment in hopper outwash	360	12.608
Sediment rejected by screening	8,713	-
Organic matter (AFDW)	41.5	1.454
Lipids	0.20	0.007

This shows that a total of 28,552 tonnes of water were discharged by the dredger during the loading period of 5.5 hours off Southwold, Suffolk in April 1998. For a cargo of 5,630 tonnes, it was estimated that 8,713 tonnes of material were rejected via the screening chute and 360 tonnes through outwash from the hopper spillways. Organic matter measured in the outwash and assumed to apply to the entire water discharge from both screening chute and hopper outwash was as much as 41.5 tonnes comprising 0.20 tonnes of lipids. The corresponding concentrations recorded in the outwash of the dredger were 12.6 grams per litre of sediment, 1.45 grams AFDW of organic matter and 0.007 grams per litre of lipids. The values for sediment in the outwash are rather lower than the 750 tonnes cited by Hitchcock & Drucker (1996) and may reflect the fact that (a) their original study was for worked deposits on the Owers Bank whereas the outwash data recorded here was for a hitherto unexploited area with a lower proportion of fine material, and (b) the technique of loading differed considerably between the two dredgers (central loading chute in 1996 as opposed to two variable loading towers in 1998).

CONCLUSIONS.

The values cited here are the first direct measurements of the concentration of organic matter in the outwash from a marine aggregates dredger, and are based on a cargo loaded from a hitherto largely unexploited site to the east of Southwold, Suffolk. The values therefore probably represent maximal concentrations for coastal deposits and are likely to be less than this in heavily-exploited areas where the biomass of benthic invertebrates has been reduced within the dredged area.

Clearly, the discharge of as much as 1.45 grams AFDW of organic matter per litre of outwash from the dredger during loading operations in areas where the benthic fauna is rich is sufficient to account for the presence of a detectable "plume" beyond the point at which inorganic suspended solids have fallen to background levels. The fact that significant quantities of lipids are associated with this material may reduce the rate of sedimentation of fragmented material and account for the commonly observed surface "sheen" at the extremity of the dispersing plume.

It is of interest to compare the organic input from dredged material described above with that from a typical detrital-based ecosystem. Kelp bed seawater in the Southern Benguela upwelling ecosystem near Cape Town, South Africa, contains 300-400 mm carbon per litre and 46-71 mg nitrogen per litre (Seiderer & Newell, 1985). Mann (1982) gives the following ratio for AFDW to carbon: 1 gram Carbon = 2.6 grams AFDW organic matter. The detrital load in the seawater of kelp beds is therefore 0.780-1.04 mg per litre. By comparison, the organic loads discharged from the dredging operation recorded above are 1.45 grams per litre. That is, about 1000 times the organic content of some of the richest detrital ecosystems in the world. Even allowing for the dispersion which must occur downstream from the dredger, it seems likely that the organic matter derived from fragmented invertebrates in the dredger outwash is sufficient to account for the enhanced species diversity and biomass of benthic invertebrates beyond the boundaries of dredged areas reported by others (see Poiner & Kennedy, 1984).

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MAFF GUIDELINES

INFORMATION REQUIRED BY UNITED KINGDOM MINISTRY OF AGRICULTURE, FISHERIES AND FOOD, DIRECTORATE OF FISHERIES RESEARCH FOR THE PURPOSES OF EVALUATING THE IMPACT OF SEABED AGGREGATE EXTRACTION ON THE MARINE ENVIRONMENT

(*from* Campbell, 1993)

BACKGROUND

1. The EC Directive on 'The assessment of the effects of certain public and private projects on the Environment' (85/337/EEC) was adopted on the 27 June 1985 and came into effect in July 1988. The effect of the Directive is to require an Environmental Assessment (EA) to be carried out, before development consent is granted, for certain types of major project which are judged likely to have significant environmental effects. Exploitation of mineral resources is identified in the Directive as an activity which might, under certain circumstances, require a supporting EA.

2. An explanatory booklet, 'Environmental Assessment: a guide to the procedures', has been prepared by the Department of the Environment in conjunction with the Welsh Office (Department of the Environment/Welsh Office, 1989). The booklet describes the legislation and the criteria which trigger the requirement to provide an EA. It also provides guidance for the content of an EA.

3. The guidelines which follow set out MAFF's requirements relevant to those elements of the environmental assessment of a proposed extraction area for which the Ministry is responsible.

INTRODUCTION

4. The [primary] effects of marine aggregate extraction on the marine environment will be physical, due to possible changes in sediment topography and type through removal of material and resettlement of fine particles. There will also be secondary biological effects as a consequence of seabed alteration and disturbance resulting in modification of benthic infaunal and epifaunal assemblages with consequent effects upon food supply for higher organisms including commercial fish and shellfish species.

5. The International Council for the Exploration of the Sea (ICES) Working Group on the Effects of Marine Aggregate Extraction upon Fisheries has conducted a comprehensive literature review on the impacts on fisheries and the marine environment in general of sand and gravel extraction (ICES, 1992). However, the significance to the wider marine environment of such dredging-induced changes will clearly depend upon the size and location of the licensed areas.

6. The considerations relevant to the deposit of dredged material at sea, including disposal site assessment, contain many common features with those of aggregate extraction. In the UK, dredged material disposal is regulated by a licensing system which reflects undertakings within the International Waste Disposal Conventions (the Oslo and London Conventions). The technical groups within these Conventions have developed specific guidance for dredged material disposal. This guidance forms the basis of the subsequent technical considerations for marine aggregate extraction.

NATURE OF THE DEPOSIT

7. The resource should be identified by its geographical location (latitude and longitude) and described in terms of:

- i the bathymetry of the area;
- ii the distance from the nearest coastline;
- iii the geological history, including the source and type of material, mean thickness of deposit, evenness of the deposit over the proposed extraction area, the nature of the underlying deposits and sediment particle size as well as the geological stability of the deposit;
- iv the natural mobility of the bottom sediments;
- v the presence of current or proposed extraction activities nearby.

8. The total quantity of material in the resource should be estimated along with proposed extraction rates and the expected lifetime of the deposit.

PHYSICAL IMPACT

9. To assess the physical impact of aggregate extraction activities, information should be provided on;

- i local hydrography including tidal and residual water movements;
- ii wind and wave patterns and characteristics, average number of storm days per year;
- iii bedload sediment transport including occurrence of sand waves;
- iv natural suspended sediment loads;
- v storm or wave-induced bottom activity;
- vi transport and settlement of fine sediment suspended by the dredging activity;
- vii dispersion of an outwash plume resulting from hopper overflow or onboard processing and its impact on normal and maximum suspended sediment load;
- viii implications for prevailing wave/current regime and local water circulation resulting from removal or creation of (at least temporarily) topographical features on the seabed;
- ix implications for the modification of longer term processes and bed-load movement;
- x nature and type of nearby coastline and implications for coastal erosion

BIOLOGICAL IMPACT

10 The principal biological impact of marine aggregate extraction is the disturbance and removal of benthic infauna and epifauna and alteration of the substrate upon which colonisation depends. Where the remnant substrate is identical to the undisturbed surface sediments (and this is normally required by licence condition), disturbance may be temporary and the extraction area will be recolonised. To assess the biological impact of aggregate extraction, the following information will probably be required:

- i an assessment of the benthic community structure(s) (species type and abundance) within the proposed extraction area which may include temporal (e.g. quarterly) as well as spatial variations;
- ii information on the fishery and shellfishery resources, including spawning areas, with particular regard to benthic spawning fish (e.g. herring and sand eels), nursery areas, over-wintering grounds for ovigerous crustaceans and known routes of migration;
- iii the predator/prey relationships between the benthos and demersal fish species (e.g. by stomach content investigations);
- iv the method of dredging, including the effect of different suction equipment upon the seabed and benthic fauna;
- v the estimated recolonisation time for the denuded sediments;
- vi a list of areas of special scientific or biological interest, such as adjacent Sites of Special Scientific Interest (SSSI), Marine Nature Reserves (MNR) and Marine Consultation Areas (MCA), Marine Special Protection Areas (SPA), sites designated under the 'Ramsar' convention, the World Heritage Convention or the UNEP 'Man and the Biosphere' Programme;
- vii areas of natural beauty or significant cultural or historical importance in or adjacent to the proposed extraction area.

INTERFERENCE WITH OTHER LEGITIMATE USES OF THE SEA

11 The assessment should consider the following in relation to the proposed programme for exploitation of the resource;

- i the number of vessels to be used and the duration of dredging campaigns (for example, daily, weekly, occasionally);
- ii seasonal commercial fishing patterns, including type of gear used, distribution, value and number of fishermen involved;
- iii shipping lanes;
- iv military exclusion zones;
- v engineering uses of the seabed (e.g. adjacent extraction activities, undersea cables and pipelines);

- vi adjacent areas of the sea designated as sites for the disposal of dredged material and sewage sludge;

- vii location of wrecks (with an indication of their historic status) and war graves;

- vii recreational uses of the area (e.g.. sport angling, diving).

EVALUATION OF IMPACT

12 In evaluating the overall impact, it will be necessary to identify and quantify the marine and coastal environmental consequences of the proposed activity and the basis of a monitoring plan as well as setting out why the proposal is not thought likely to effect other interests of acknowledged importance to the area.

13 These consequences can be summarised as an Impact Hypothesis, which will draw on the results of earlier studies of environmental characteristics and their variability. The Impact Hypothesis will also indicate where measures need to be taken to mitigate the effects of the proposed dredging or associated operations.

14 It will then be necessary to consider the steps that might be taken to mitigate the effects of extraction activities. This may include:

- i the selection of dredging equipment and timing of the dredging operations to limit impact on benthic communities and spawning cycles;

- ii modification of dredging depth limit changes to hydrodynamics and sediment transport;

- iii zoning the area to be licensed or scheduling extraction campaigns to protect sensitive fisheries or to respect access to traditional commercial fisheries.

15 It may also be necessary to demonstrate the need to exploit the resource in question, through careful, comparative consideration of local, regional and national need for the material in relation to the identified impacts of the proposal and the relative environmental costs of provision from other sources, both marine and on land.

MONITORING

16 **Definition:** In the context of assessing and controlling the environmental effects of marine aggregate extraction, monitoring is the repeated measurement of an effect whether direct or indirect on the marine environment.

17 Monitoring of the marine environment is generally undertaken for the following reasons;

i to establish whether licence conditions are being observed;

ii to establish whether licensing conditions are preventing extraction activities having adverse effects on the marine environment;

iii to provide the necessary evidence to demonstrate that the control measure applied are sufficient to ensure that any lasting environmental damage does not result from exploitation of marine resources;

iv to improve the basis on which licence applications are assessed by improving knowledge of field effects which are not readily estimated by laboratory or literature assessment.

18. Monitoring operations are expensive for they require considerable resources both at sea and in subsequent sample and data processing. In order to approach a monitoring programme in a resource-effective manner, it is essential that the programme should have clearly defined objectives, that measurements made can meet those objectives, and that the results be reviewed at regular intervals in relation to those objectives. The monitoring scheme should then be continued, reviewed or even terminated.

19. **Impact Hypothesis**: The Impact Hypothesis prepared from the environmental assessment summarises the effects of the proposal on the marine environment. It is an important element in the establishment of a monitoring programme. Before any monitoring programme is drawn up and any measurements are made, the following questions should be addressed;

- i what measurements are necessary to meet specified objectives?
- ii what is the purpose of monitoring a particular variable or biological effect?
- iii in what environmental compartment or at what locations can the measurements be made cost effectively?
- iv how many measurements are necessary to meet specified objectives
- v for how long should the measurements continue to be made to meet the objective?
- vi what should be the temporal and spatial scale of measurements be made to test the hypothesis?

20. The extraction of marine aggregate has a primary impact at the seabed. Thus, although a consideration of water column effects cannot be discounted in the early stages of planning the monitoring, it is often possible to restrict subsequent monitoring to the seabed.

21. Where it is considered that the effects will be largely physical, monitoring may be based on remote methods such as sidescan sonar to identify changes in the character of the seabed. These measurements may require a certain amount of sediment sampling to establish ground truth.

22. Biological sampling to assess changes in the benthic community structure may also be appropriate provided there is a scientific basis for the interpretation of the resulting data.

23. In order to assess the impact, it will be necessary to take account of any natural biological variability. This is best achieved by comparing the physical or biological status of the affected areas with reference sites located away from the extraction site. Such reference sites can be identified during the preparation of the Impact Hypothesis.

24. The spatial extent of sampling will need to take into account the area designated for extraction, any possibility of operating outside the licensed area and the mobility of fine material raised into suspension by the dredging activity.

25. Since the effects of marine aggregate extraction will have some similarities in different sites, it will be appropriate to conduct biological monitoring programmes at a few carefully chosen sites. It is also appropriate to consider 'far afield' effects of extraction such as the relationship between spawning grounds and areas of recruitment. Measurements relating to the timing of extraction should be conducted at each site.

26. Concise statement of monitoring activities should be prepared. Reports should detail the measurements made, results obtained, their interpretation and how these data relate to the monitoring objectives. The frequency of monitoring will depend on the aims and will be related to the scale of extraction activities and the anticipated period of consequential environmental changes which may extend beyond the cessation of extraction activities.

PREPARATION OF ENVIRONMENTAL STATEMENT

27. The environmental statement should describe the information used as the basis of the environmental assessment and should set out the results of the assessment in the form of an Impact Hypothesis. It will detail all the significant effects of the proposal that have been identified and briefly explain why the proposal is unlikely to affect other interests or areas of acknowledged importance in the vicinity of the proposal.

28. The environmental statement should set out any measures or changes to the proposal designed to ameliorate the effects of the proposal that were identified in the Impact Hypothesis. Where it is not possible to ameliorate the effects of the proposal the statement should provide details of the reasons why the benefits of the proposal outweigh its environmental effects.

29. The environmental statement should describe the monitoring needed to ensure that the Impact Hypothesis is valid and any ameliorative measures are effective.

EXAMPLE OF A SCOPING DOCUMENT FOR ENVIRONMENTAL ASSESSMENT FOR A MARINE DREDGING PROPOSAL (*from* ICES, 1993)

SCOPE

The form and content of the Environmental Statement are anticipated to be as follows;

1 Project Details

⇒ location and size of licence area;
⇒ volume of material to be extracted;
⇒ type of material to be extracted;
⇒ proposed method of dredging;
⇒ vessel numbers and movements;
⇒ dredging programme, including phasing, period of working and frequency;
⇒ discharge of fines - quantity and composition;
⇒ onshore proposals - landings and onward transportation;
⇒ project related employment.

2 The Site and its Environment

a) Physical Aspects

⇒ bathymetry of licence areas and surroundings;
⇒ geological history - type of material, mean thickness and evenness across the area, nature of underlying deposits;
⇒ local hydrography - currents, tides and residual water movements, wave patterns, meteorological influences such as storm frequency;
⇒ stability, mobility and turbidity of bottom sediments and natural suspended sediment loads;
⇒ water quality and existing pollution levels.

b) Biological Aspects

⇒ the benthic community structure - species type and abundance, temporal and spatial variations;
⇒ the fishery and shellfishery resource - including sole areas, nursery areas, over-wintering grounds for ovigerous crustaceans and known routes of migration;
⇒ predator/prey relationships between the benthos and demersal fish species;
⇒ context of the biotic resource in relationship to the surrounding area - i.e. its *relative* importance.

c) Human Environment

⇒ economic importance of the fishery and shellfishery resource - catch and landing statistics, value and employment levels;
⇒ other dredging activity in adjacent areas - existing and/or proposed;
⇒ waste disposal, including sewage sludge;
⇒ offshore oil and gas industry - adjacent exploration and/or production activity, pipelines;

- ⇒ other seabed features - cables, wrecks, war graves;
- ⇒ shipping lanes/navigation requirements;
- ⇒ MoD exclusion areas and uses;
- ⇒ leisure activities in the area.

d) The Policy Framework

- ⇒ statutory designations;
- ⇒ relevant EC directives, conventions and agreements;
- ⇒ UK Government Policy, Mineral Planning Guidance Notes and aggregates policy.

3 Assessment of Effects

An analysis of the likely significant effects, including a description of the forecasting methods used.

a) Physical Effects

- ⇒ effects of dredging directly on the seabed - including condition of the substrate after dredging;
- ⇒ effects of removal of material on the natural sediment movement regime and topographical features on the seabed, including potential effects on coastal erosion and deposition processes;
- ⇒ implications of changes in topographical features on prevailing wave/current regime and local water circulation;
- ⇒ information on predicted transport and settlement of fines suspended by the dredging activity, from an outwash plume or from on-board screening/grading.

b) Biological Effects

- ⇒ effects of dredging activity on the benthic infauna and epifauna including any transboundary effects;
- ⇒ estimated recolonisation time for the denuded sediments;
- ⇒ effects of the settlements of fines on the benthic community over the predicted affected area;
- ⇒ further analysis of the effects on the fishery and shellfishery resources, including spawning areas, with particular regard to sole fisheries, crustaceans, and the predator/prey relationship between the benthos and demersal fish species.

c) Effects on Human Environment

- ⇒ analysis of the consequences of any predicted changes in fishing patterns, including landings, value and employment;
- ⇒ effects on, or conflicts with, other existing or proposed sea uses - adjacent dredging areas, oil and gas industries, dumping, navigation, MoD activities, cables and pipelines, wrecks etc.;
- ⇒ employment in dredging activities.

d) Other Indirect and Secondary Effects

⇒ indirect employment implications at receiving ports;
⇒ onward transportation from receiving ports.

4 Mitigation of Effects

The steps proposed to mitigate the effects of extraction activities. These may include:

⇒ measures to limit impact on benthic communities and spawning cycles through the selection of dredging equipment and timing of dredging operations;
⇒ measures to protect fisheries interests through zoning the licence area and/or scheduling extraction to avoid the most sensitive seasons;
⇒ modification of dredging depths to limit changes to hydrodynamics and sediment transport.

5 Accident, Risks and Hazards

⇒ measures to safeguard against identified risks - primarily shipping risks

6 Monitoring

⇒ setting of objectives for a monitoring programme;
⇒ proposals for monitoring arrangements before, during and after dredging operations, in order to meet the specified objectives.

7 Non-technical Summary

⇒ a non-technical summary of the information provided in the ES